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(54) **PRINTING APPARATUS**

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(73) Assignee: **Seiko Epson Corporation**, Tokyo (JP)

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
B41J 2/165 (2006.01)
B41J 2/175 (2006.01)

(52) **U.S. Cl.** **347/23**; 347/86

(58) **Field of Classification Search** 347/7, 22, 347/23, 85, 86
See application file for complete search history.

(56) **References Cited**

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Primary Examiner — An H Do

(57) **ABSTRACT**

A printing apparatus includes a recording head that prints an image and an ink cartridge that stores ink to the recording head. The ink cartridge includes an ink pack and an ink-end sensor that detects an ink-end point based on the pressure of ink supplied from the ink pack. The ink pressure corresponding to the ink-end point detected by the ink-end sensor is set to a first pressure that is the minimum pressure near an outlet of the ink cartridge at which the recording head can print an image of predetermined quality. A determining unit permits starting of a printing or cleaning operation in response to a command issued before the ink-end sensor detects the ink-end point and prohibits starting of a printing or cleaning operation in response to a command issued after the ink-end sensor has detected the ink-end point.

6 Claims, 11 Drawing Sheets

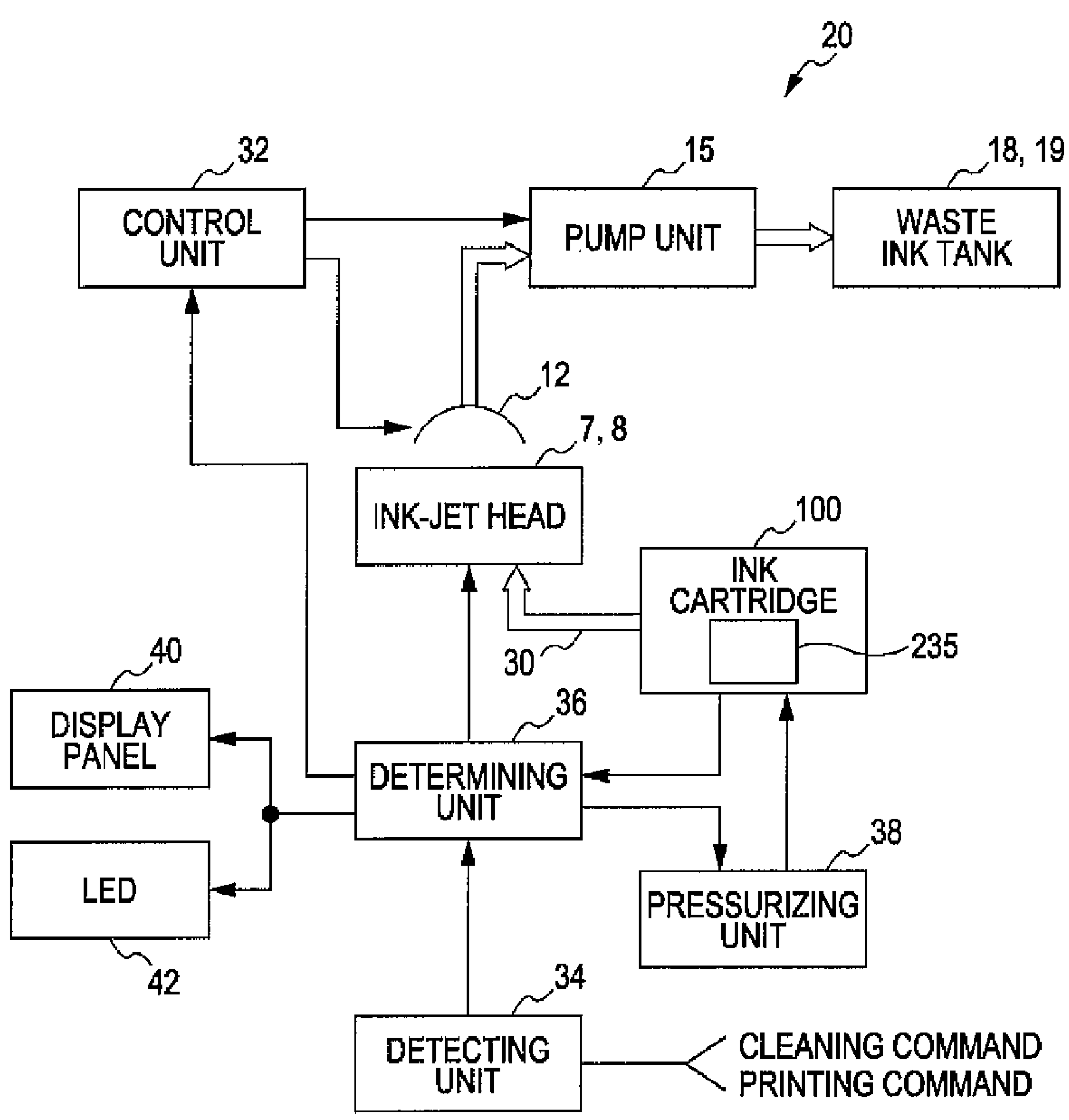


FIG. 1

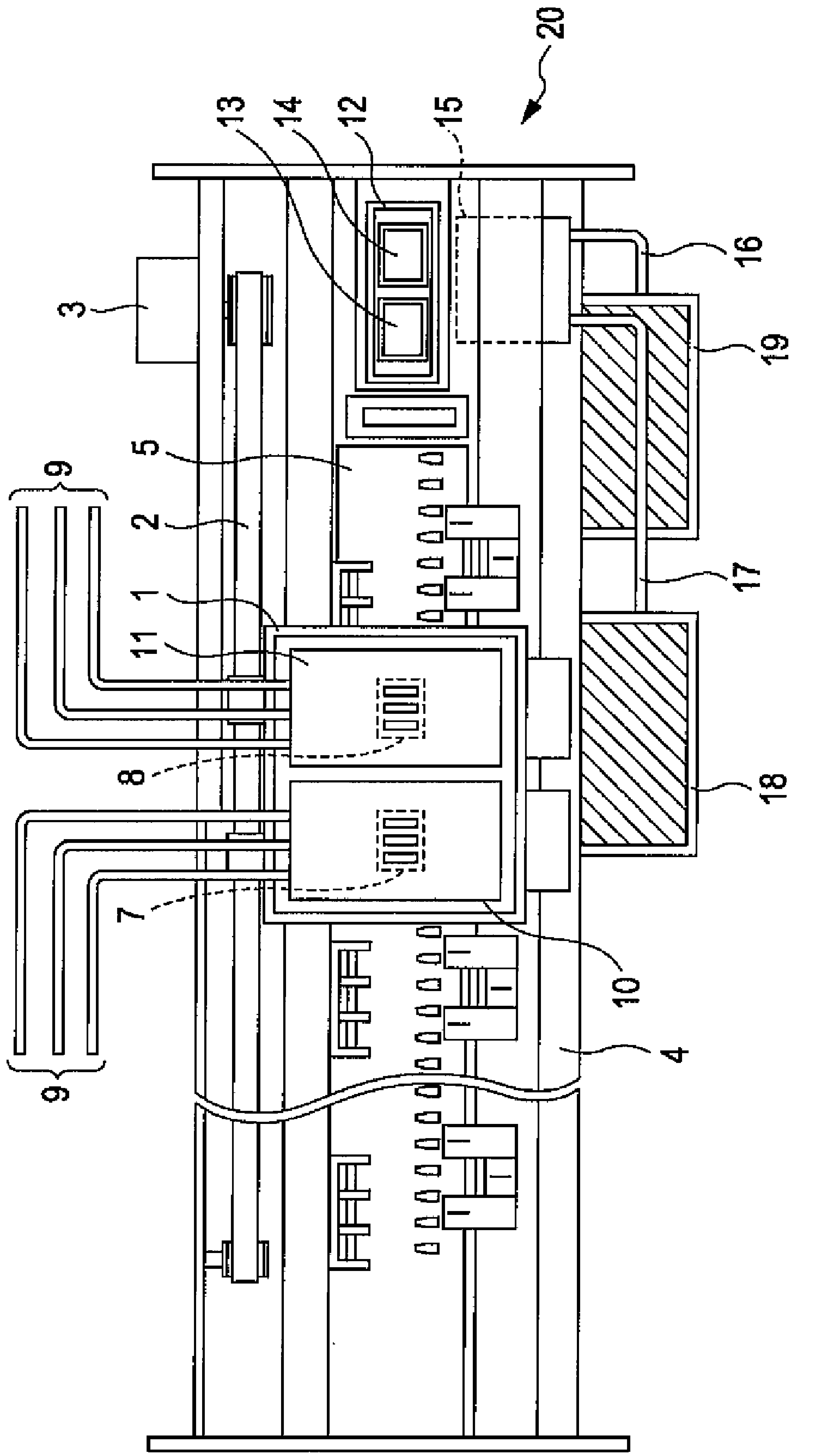


FIG. 2

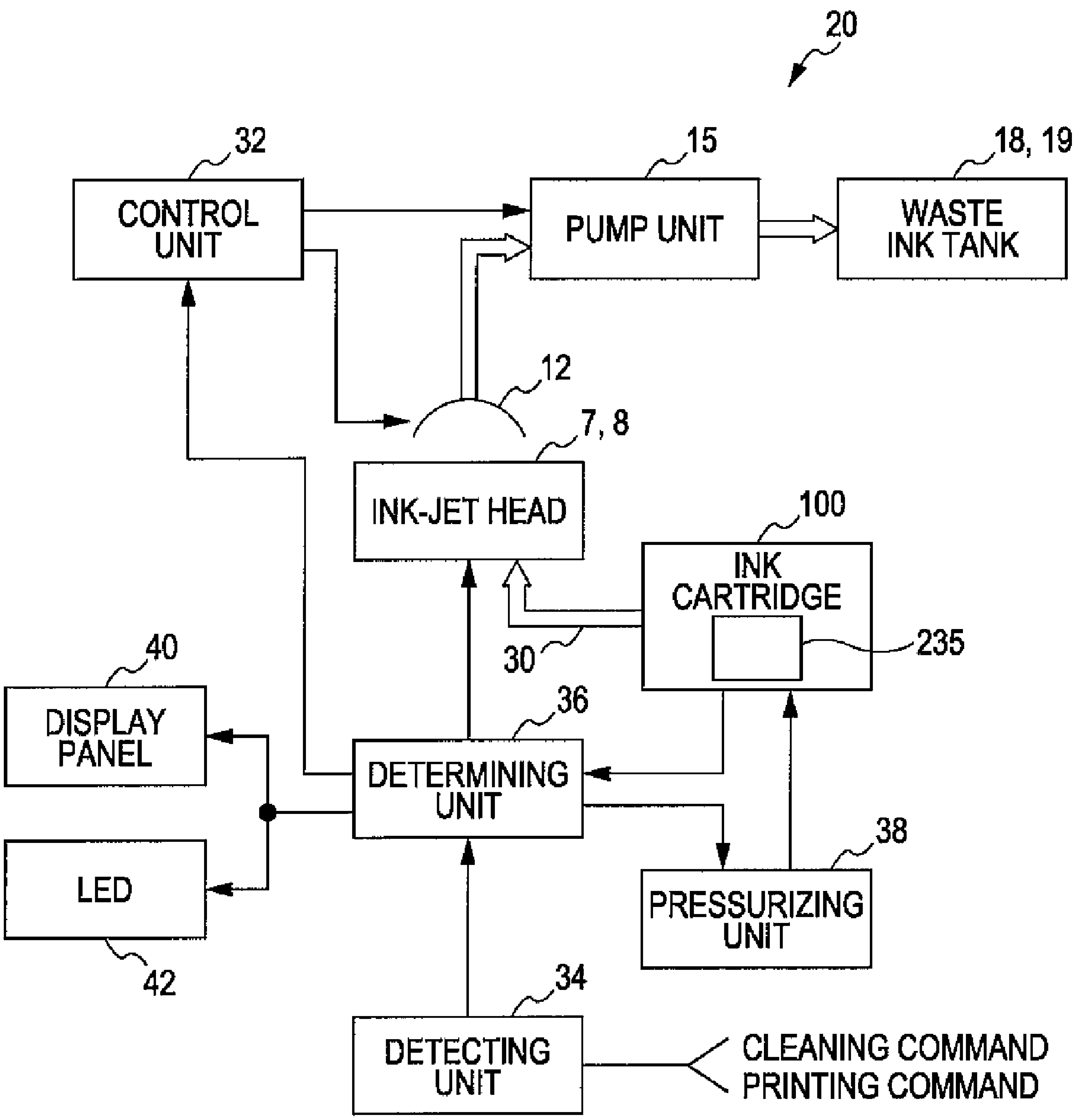

20
32
CONTROL UNIT
15
PUMP UNIT
18, 19
WASTE INK TANK
12
7, 8
INK-JET HEAD
100
INK CARTRIDGE
235
30
40
DISPLAY PANEL
36
DETERMINING UNIT
LED
42
38
PRESSURIZING UNIT
34
DETECTING UNIT
CLEANING COMMAND
PRINTING COMMAND

FIG. 3

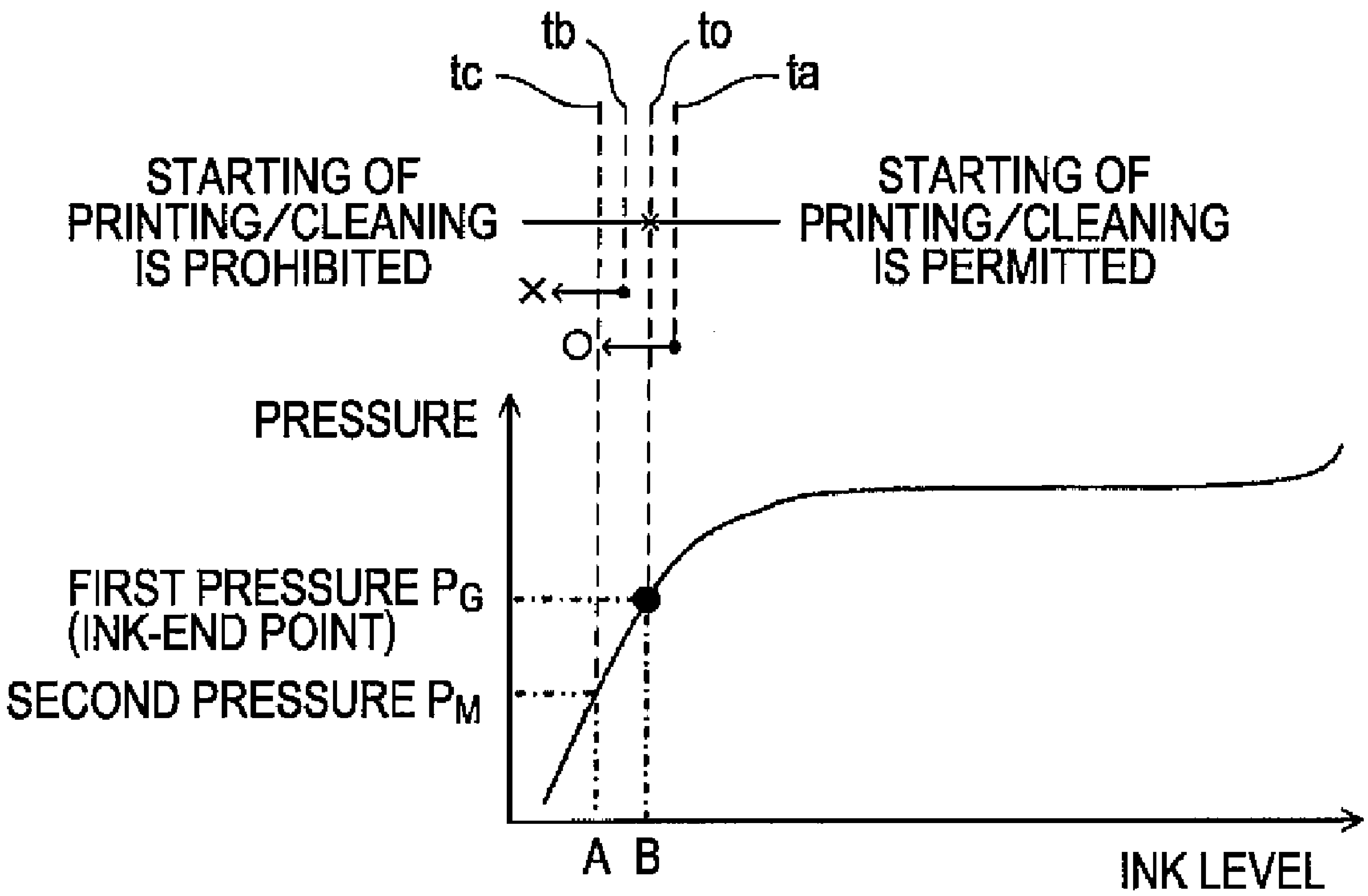

tb
to
tc
ta
STARTING OF PRINTING/CLEANING IS PROHIBITED
STARTING OF PRINTING/CLEANING IS PERMITTED
×
O
PRESSURE
FIRST PRESSURE PG (INK-END POINT)
SECOND PRESSURE PM
A
B
INK LEVEL

FIG. 4

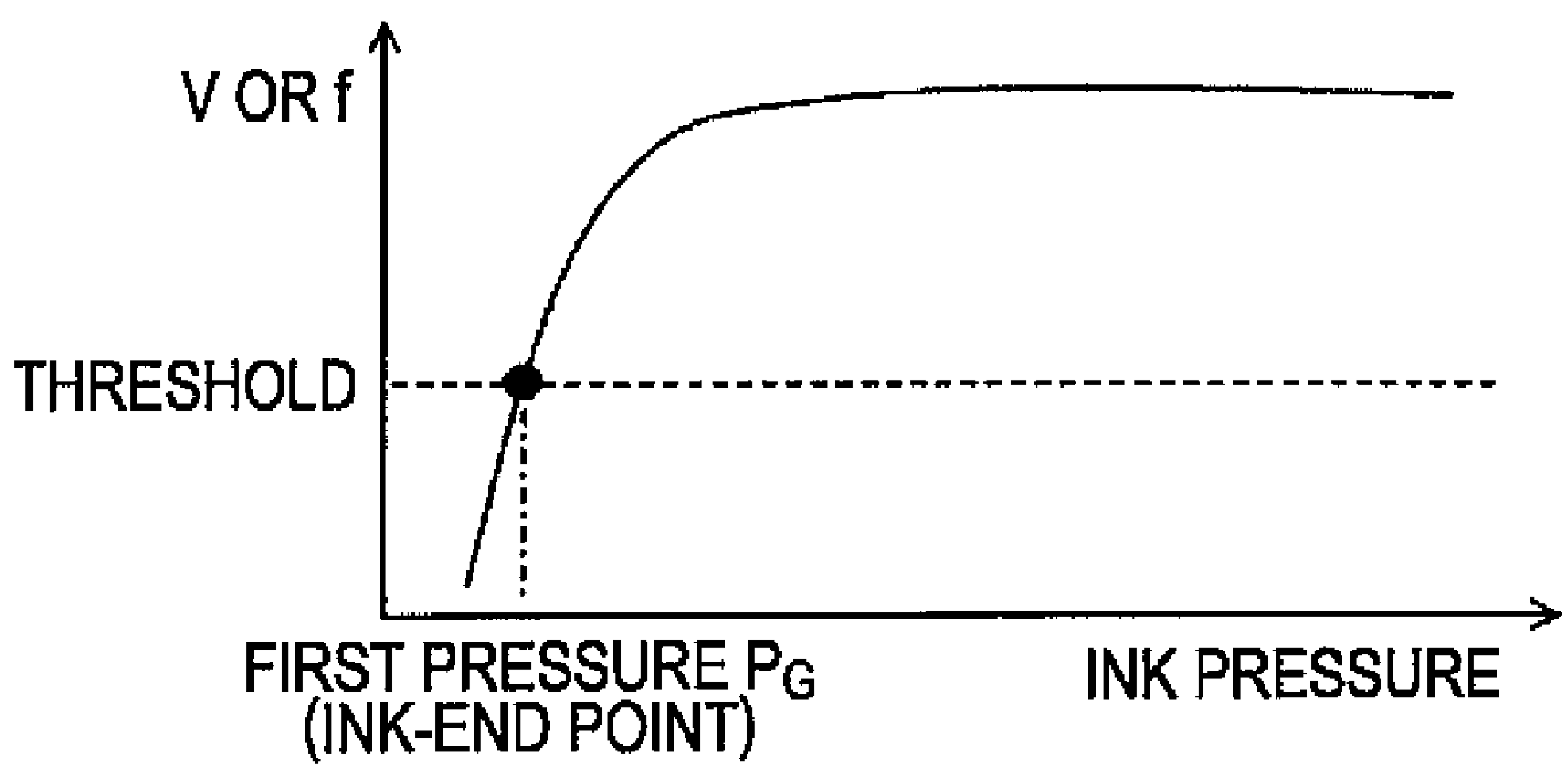

V OR f
THRESHOLD
FIRST PRESSURE PG (INK-END POINT)
INK PRESSURE

FIG. 5

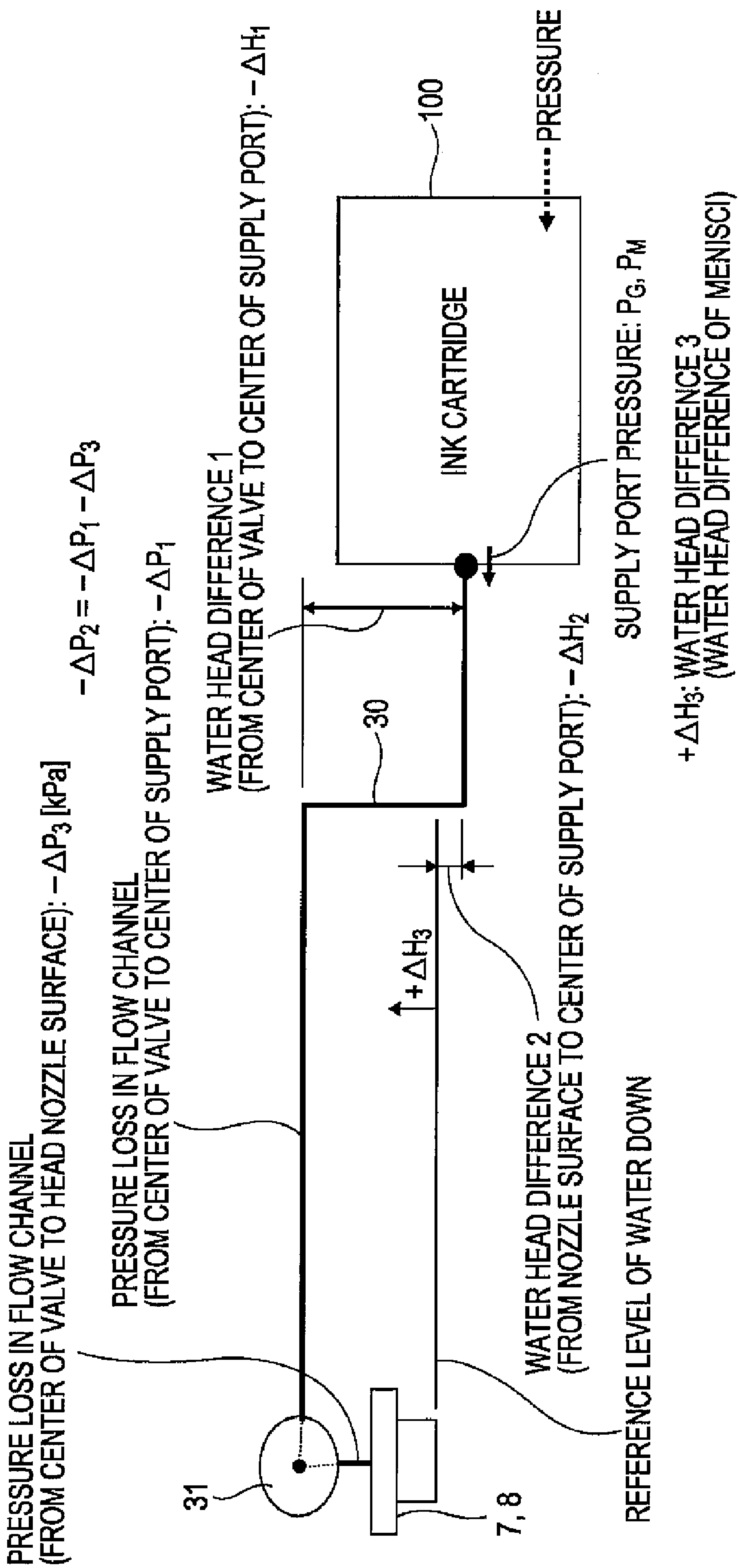

PRESSURE
100
INK CARTRIDGE
SUPPLY PORT PRESSURE: P_G, P_M
+ΔH_3: WATER HEAD DIFFERENCE 3
(WATER HEAD DIFFERENCE OF MENISCI)
WATER HEAD DIFFERENCE 1
(FROM CENTER OF VALVE TO CENTER OF SUPPLY PORT): $-\Delta H_1$
$-\Delta P_2 = -\Delta P_1 - \Delta P_3$
PRESSURE LOSS IN FLOW CHANNEL
(FROM CENTER OF VALVE TO CENTER OF SUPPLY PORT): $-\Delta P_1$
PRESSURE LOSS IN FLOW CHANNEL
(FROM CENTER OF VALVE TO HEAD NOZZLE SURFACE): $-\Delta P_3$ [kPa]
30
+ΔH_3
WATER HEAD DIFFERENCE 2
(FROM NOZZLE SURFACE TO CENTER OF SUPPLY PORT): $-\Delta H_2$
REFERENCE LEVEL OF WATER DOWN
31
7, 8

FIG. 6

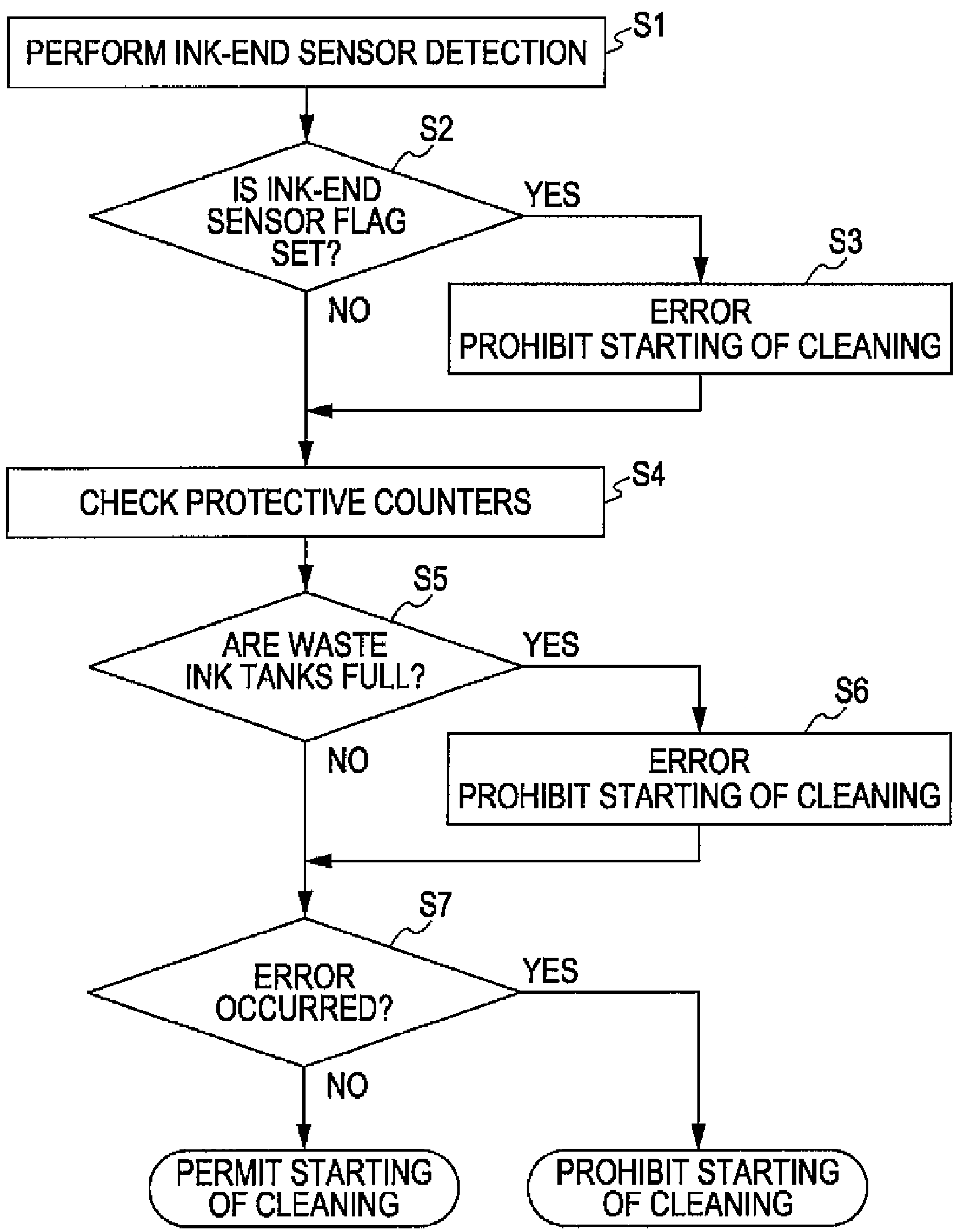
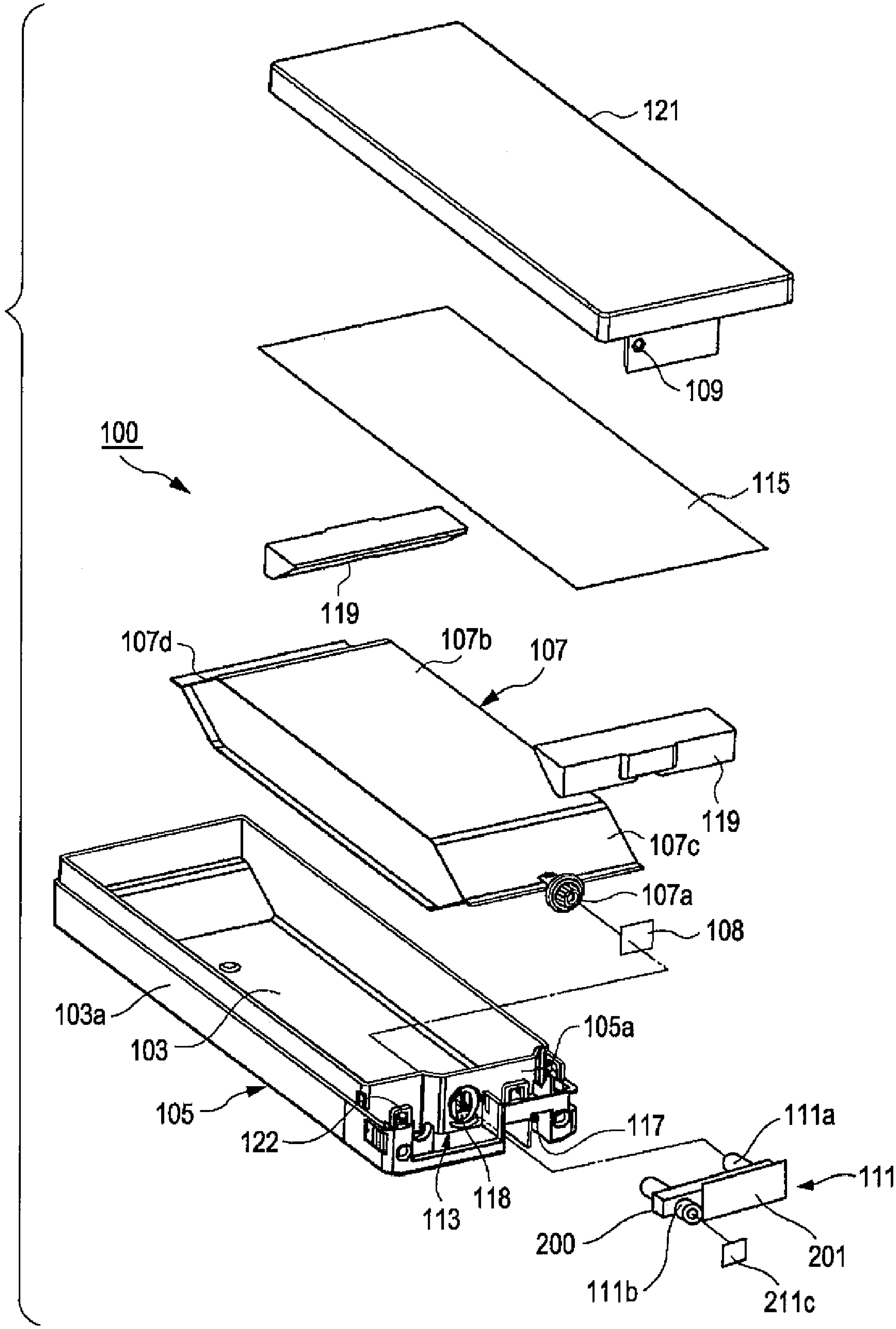

PERFORM INK-END SENSOR DETECTION
S1
S2
IS INK-END SENSOR FLAG SET?
YES
NO
S3
ERROR
PROHIBIT STARTING OF CLEANING
CHECK PROTECTIVE COUNTERS
S4
S5
ARE WASTE INK TANKS FULL?
YES
NO
S6
ERROR
PROHIBIT STARTING OF CLEANING
S7
ERROR OCCURRED?
YES
NO
PERMIT STARTING OF CLEANING
PROHIBIT STARTING OF CLEANING

FIG. 7



121
109
100
115
119
107d
107b
107
119
107c
107a
108
103a
103
105a
105
122
117
111a
111
113
118
200
201
111b
211c

FIG. 8

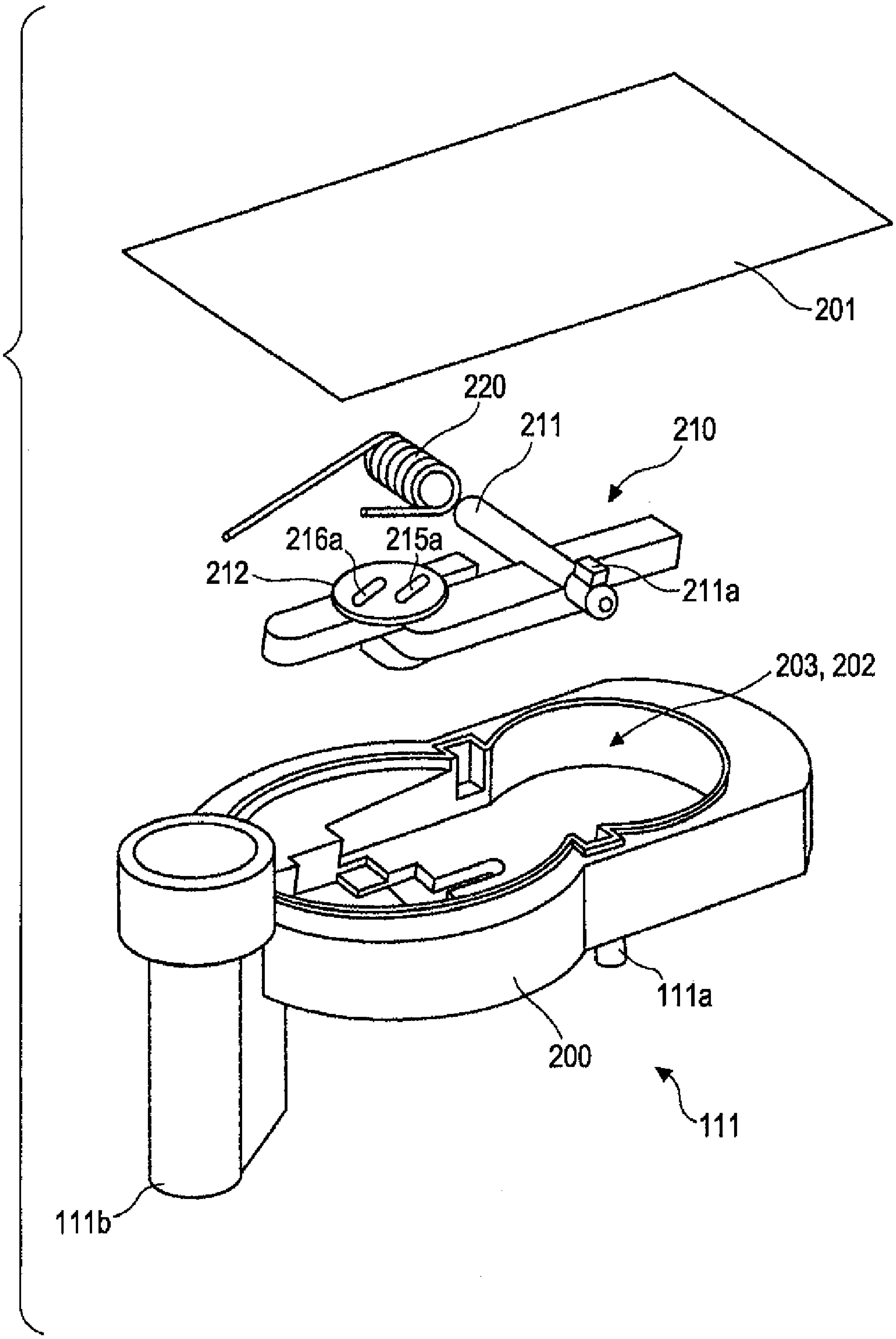
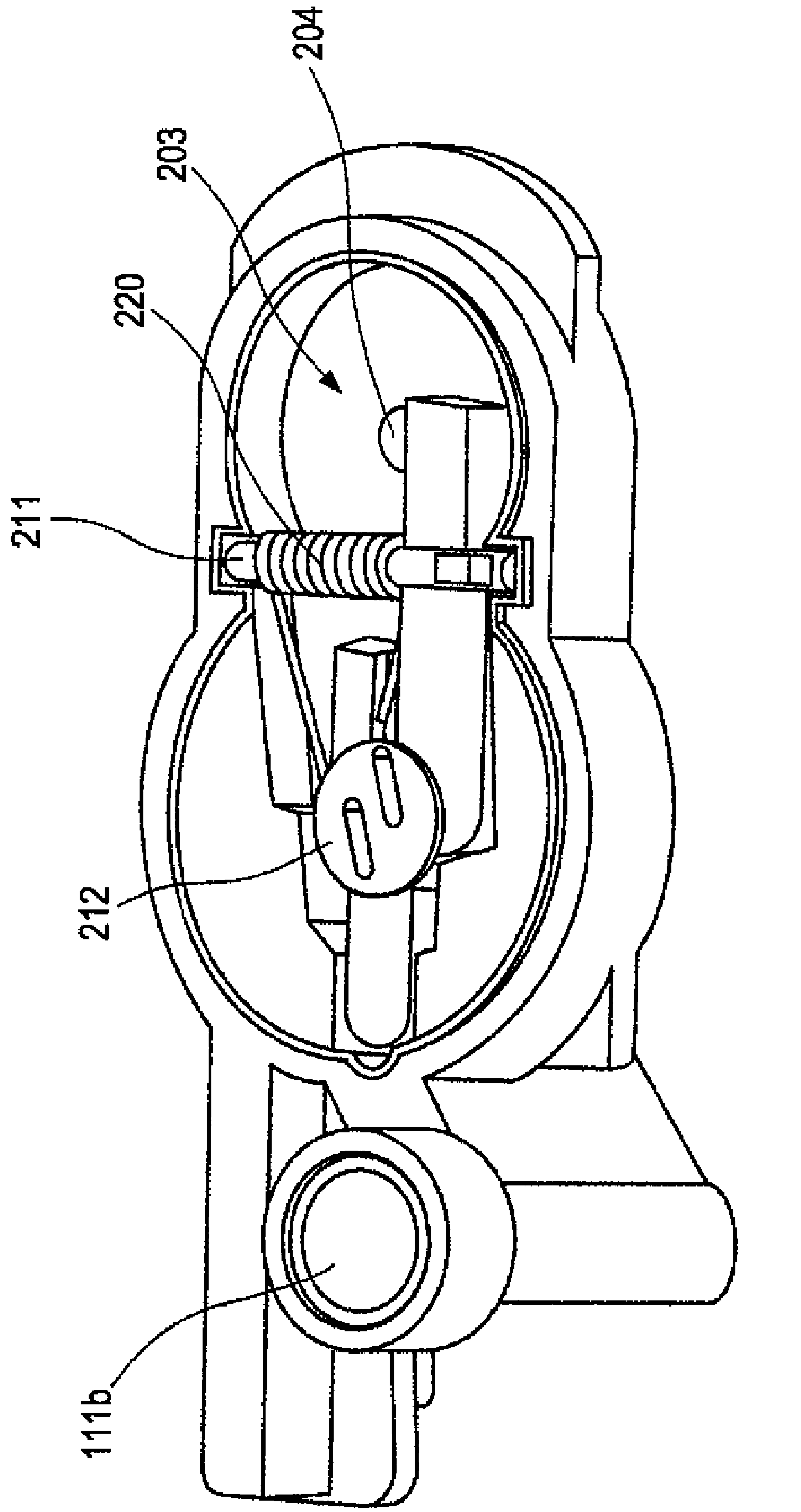
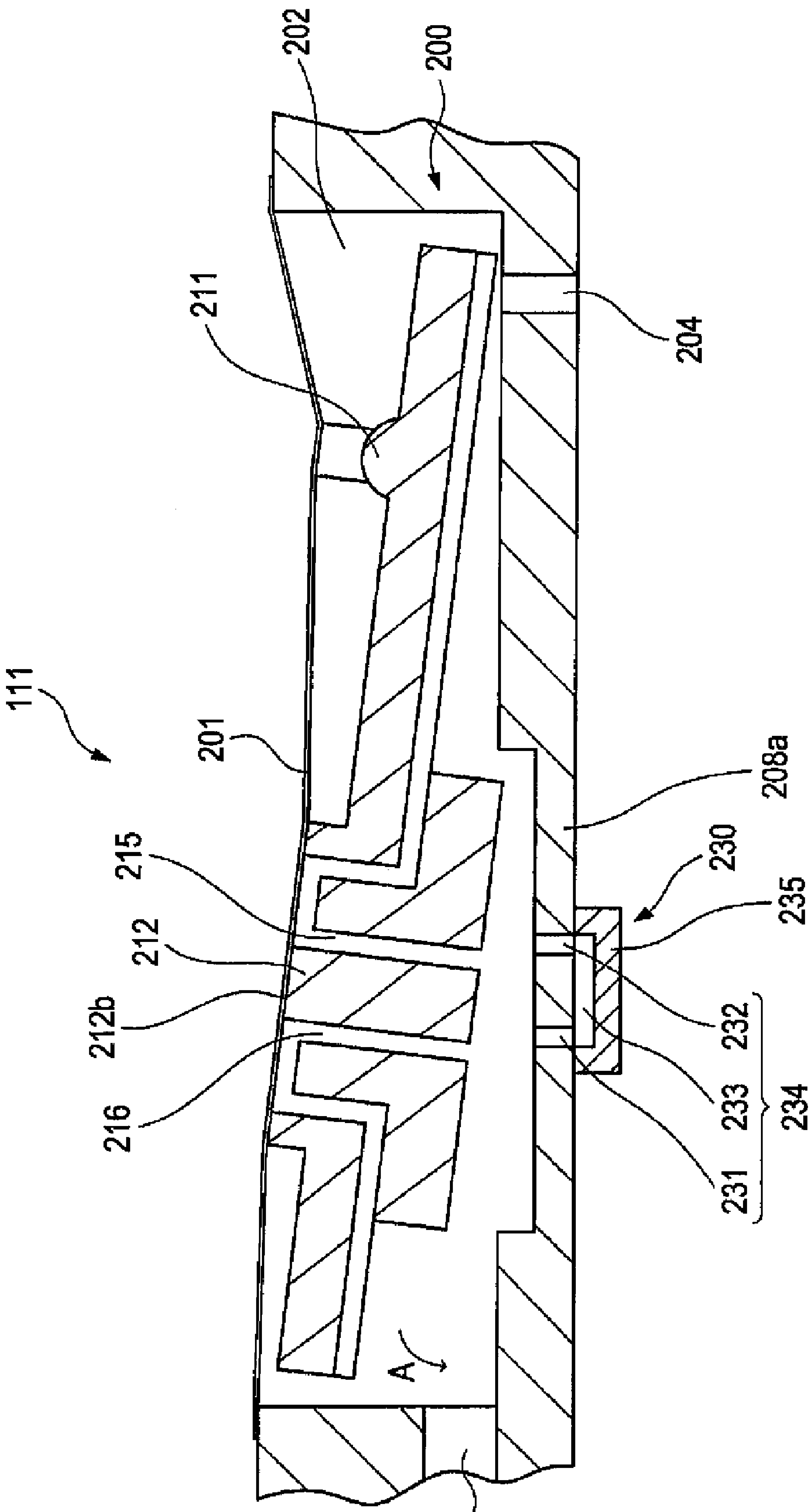


FIG. 9





111
200
202
204
211
201
215
212
212b
216
208a
230
235
232
233
231
234
A
205

FIG. 10

FIG. 11

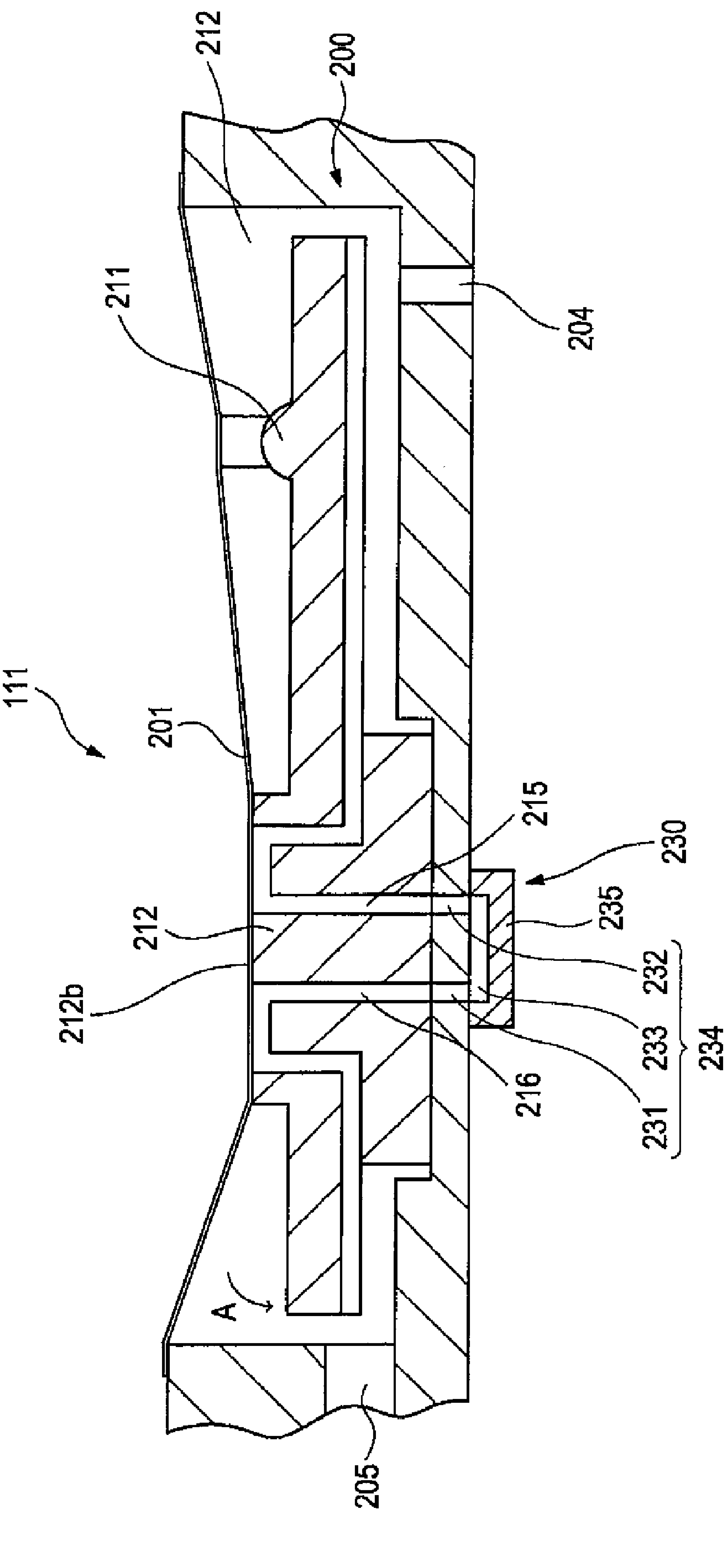

111
200
212
211
204
201
215
230
235
212
232
212b
233
234
216
231
A
205

FIG. 12A

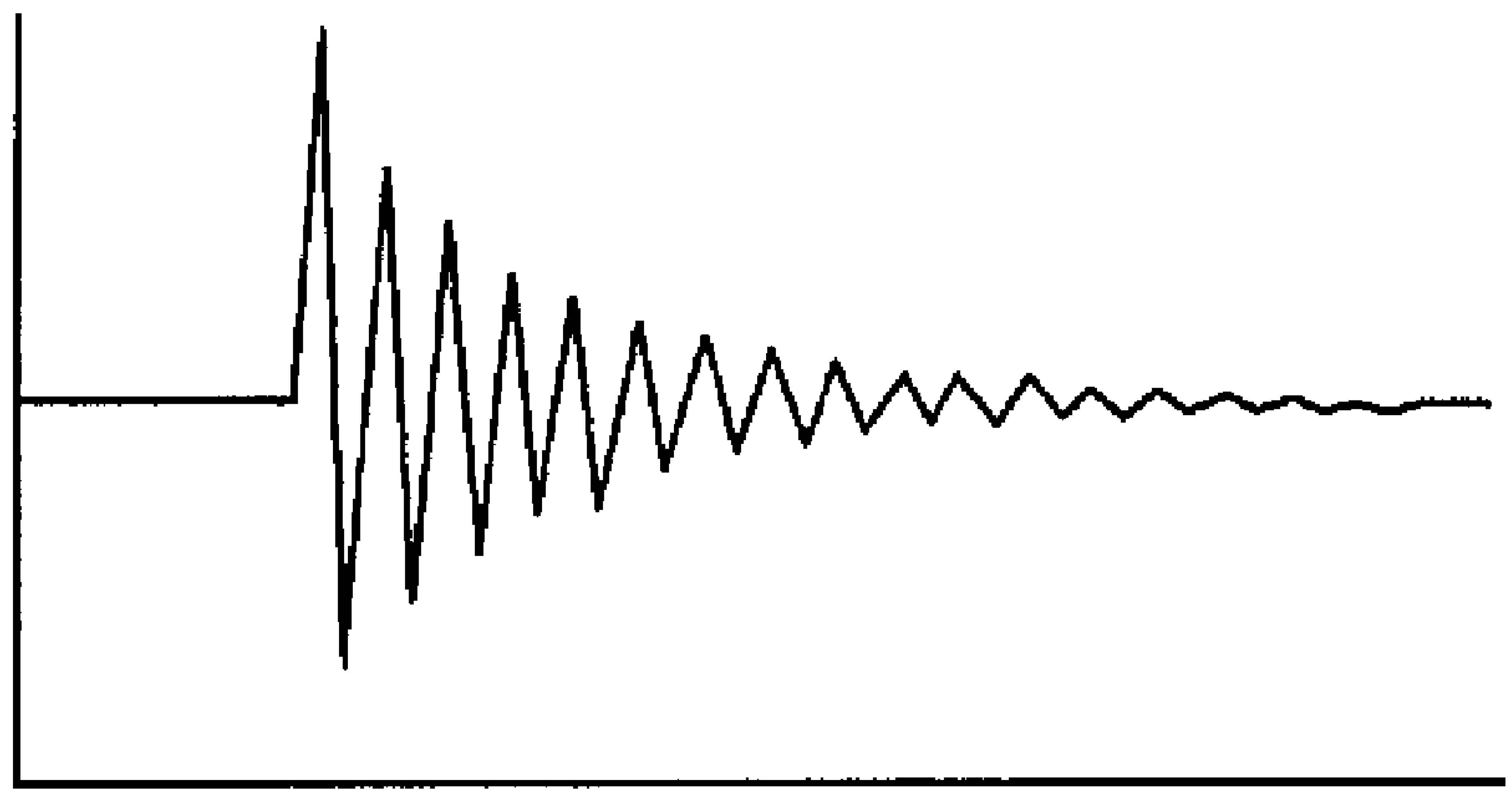
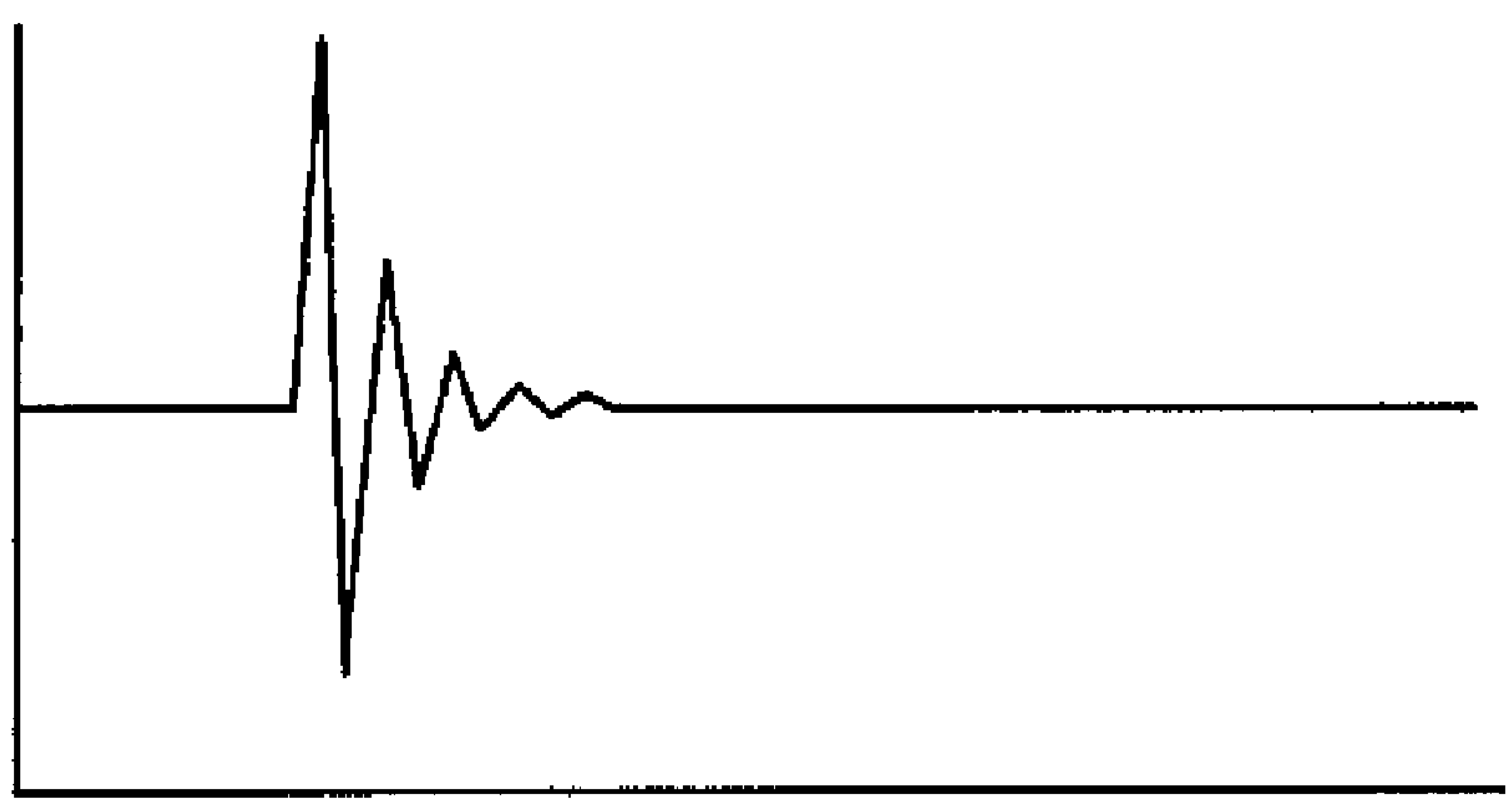


FIG. 12B



PRINTING APPARATUS

BACKGROUND

1. Technical Field

The present invention relates to printing apparatuses suitable for use as, for example, printers, and particularly to improvements in determination of whether or not a cleaning operation for recording heads is started at a low ink level.

2. Related Art

A type of printer is known that performs printing by ejecting ink supplied from an ink cartridge (ink tank) from a recording head onto a recording medium. This type of printer can fail to print successfully because of phenomena such as nozzle clogging due to increased ink viscosity resulting from evaporation of ink solvent from nozzle orifices of the recording head, deposition of dust on the nozzle orifices, and intrusion of bubbles into the nozzles upon replacement of the cartridge.

To recover the printer from such phenomena, as is known in the related art, a cleaning operation is performed by sucking ink from the nozzles of the recording head to eliminate the problems such as clogging, deposition of dust, and intrusion of bubbles at the nozzles of the recording head.

Specifically, as discussed in JP-A-2000-153622 (Patent Document 1), JP-A-2005-104089 (Patent Document 2), and JP-A-11-5300 (Patent Document 3), the cleaning operation is performed by a cleaning mechanism provided in a printer. The cleaning mechanism includes a cap, an ink drain channel communicating with the cap, and a pump provided somewhere in the ink drain channel. The nozzles of the recording head are covered with the cap before the pump is driven to reduce the inner pressure of the cap via the ink drain channel. This causes ink to be sucked from the nozzles of the recording head and drained into a waste ink tank, thus eliminating the problems such as nozzle clogging.

During the cleaning operation, the ink supply from the ink cartridge must not be interrupted because, for example, the ink drained into the cap, which has therefore been contaminated, would flow back, thus complicating maintenance.

Accordingly, whether or not the cleaning operation is permitted is determined with respect to the ink level. According to JP-A-2000-296627 (Patent Document 4), an ink-end level is set on the basis of the amount of ink stored in the ink tank, and notification requesting replacement of the ink tank is provided when a total ink consumption calculated by a soft counter or dot counter exceeds the ink-end level (see paragraphs 0044 and 0053-0055 of Patent Document 4). The total ink consumption is the sum of the cumulative ink consumption count and the consumption count for the next cleaning operation. The ink-end level is a predetermined level depending on the type of ink cartridge.

The above method, however, results in a significant cumulative error because the soft counter or dot counter counts the total ink consumption in such a manner that safety ejection is ensured to prevent ejection failure. This means that the determination that the cleaning operation is prohibited is made even if the ink actually remains in the ink tank. Hence, the replacement of the ink tank is requested even if the ink level is actually sufficient for cleaning. This applies not only to cleaning but also to printing.

Another approach uses an ink-level sensor built into an ink tank (ink cartridge) to detect ink depletion and provide notification requesting replacement of the ink tank. In the related art, however, the notification requesting replacement of the ink tank is provided before the sensor detects ink depletion because the total ink consumption exceeds the ink-end level.

In the second embodiment discussed in Patent Document 4, the ink tank is provided with a detection switch that is actuated by a mechanical ink-end sensor. A near-end point is detected when the detection switch is actuated, and afterwards a soft counter or dot counter is used to permit printing or cleaning on the basis of the amount of ink to be used in printing or cleaning (see paragraphs 0060-0066 and FIGS. 5 and 6 of Patent Document 4).

SUMMARY

An advantage of some aspects of the invention is that it provides a printing apparatus in which a cleaning operation is permitted until an ink-end sensor, mounted on an ink cartridge, that operates on the basis of ink pressure detects ink depletion with respect to a modified ink-end point.

A printing apparatus according to an aspect of the invention includes a recording head that prints an image in response to a printing command, an ink cartridge communicating with the recording head and storing an ink to be supplied to the recording head, an ink channel extending between the recording head and the ink cartridge, a cleaning mechanism that cleans the recording head with the ink stored in the ink cartridge in response to a cleaning command, and a determining unit that determines whether or not the recording head is permitted to start a printing operation and whether or not the cleaning mechanism is permitted to start a cleaning operation on the basis of the ink level of the ink cartridge. The ink cartridge includes an ink pack from which the ink is introduced under pressure and an ink-end sensor that detects an ink-end point on the basis of the pressure of the ink supplied from the ink pack under pressure. The ink pressure corresponding to the ink-end point detected by the ink-end sensor is set to a first pressure that is the minimum pressure near an outlet of the ink cartridge at which the recording head can print an image of predetermined quality. The determining unit permits starting of a printing or cleaning operation in response to a command issued before the ink-end sensor detects the ink-end point and prohibits starting of a printing or cleaning operation in response to a command issued after the ink-end sensor has detected the ink-end point.

In the above printing apparatus, the determining unit permits starting of a printing or cleaning operation in response to a command issued before the ink-end sensor detects the ink-end point (first pressure). In this case, the printing or cleaning operation may end after the ink-end sensor has detected the ink-end point. During printing, the ink-end sensor performs the detection operation regularly and determines that the ink has been depleted when it detects the ink-end point. The determining unit, on the other hand, prohibits starting of a printing or cleaning operation in response to a command issued after the ink-end sensor has detected the ink-end point. The determining unit can thus determine whether or not a printing or cleaning operation is permitted at a low ink level with respect to the ink-end point based on the ink pressure, which correlates with the ink level, without necessarily depending on a soft counter or dot counter. To meet various practical situations, nevertheless, a soft counter or dot counter may be used in combination, although a soft counter or dot counter used for another purpose is not necessary after the detection of the ink-end point and may therefore be stopped or reset after the detection of the ink-end point.

In the above printing apparatus, preferably, the ink channel includes a pressure-reducing valve upstream of the recording head, and the first pressure is calculated from the maximum pressure loss between the outlet of the ink cartridge and the center of the pressure-reducing valve in printing and the water head difference between the outlet of the ink cartridge and the center of the pressure-reducing valve. The pressure-reducing valve is a pressure control valve that opens when the pressure on the recording head side falls below a predetermined pressure. The pressure on the cartridge side does not affect the opening and closing of the pressure-reducing valve.

Although the first pressure may be set to the minimum pressure near the outlet of the ink cartridge at which the ink can be ejected from the recording head to print an image of predetermined quality, it may be calculated, as described above, from the pressure loss in the flow channel from the outlet of the ink cartridge to the center of the pressure-reducing valve in printing and the water head difference between the outlet of the ink cartridge and the center of the pressure-reducing valve. If the first pressure is set in view of the effects of the pressure loss and the water head difference in the flow channel, the ink can be constantly pumped to the pressure-reducing valve without a deficiency of ink supply. This allows the recording head to constantly eject droplets of predetermined size, thus ensuring print quality.

In the above printing apparatus, preferably, the first pressure is higher than lower limit pressure of a second pressure near the outlet of the ink cartridge below which a meniscus collapses in the recording head, and the amount of ink that can be supplied from the ink cartridge while the ink pressure changes from the first pressure to the lower limit pressure of second pressure is greater than or equal to the amount of ink consumed in cleaning.

The lower limit pressure of second pressure is the critical pressure at which the meniscus does not collapse in the nozzle surface of the recording head and no air intrudes; the ink ejection operation cannot be performed below the lower limit pressure of second pressure. The ink ejection operation can be prohibited below the second pressure if only starting of a printing or cleaning operation in response to a command, issued before the ink-end point (first pressure) is detected, is permitted and the amount of ink that can be supplied from the ink cartridge while the ink pressure changes from the first pressure to the lower limit pressure of second pressure is greater than or equal to the amount of ink consumed in cleaning. The amount of ink consumed in printing is often much greater than the amount of ink consumed in cleaning, but problems such as ejection failure can be avoided because the ink-end detection operation can be performed regularly (e.g., at the timing of regular flushing) during printing.

In the above printing apparatus, preferably, the second pressure is calculated from the meniscus strength of a nozzle of the recording head, the maximum pressure loss between the outlet of the ink cartridge and the recording head in printing, and the water head difference between the outlet of the ink cartridge and an outlet of the recording head. In this case, the second pressure can be set to a pressure at which the meniscus does not collapse in the recording head when it ejects the ink in cleaning.

In the above printing apparatus, the ink cartridge may include an ink-level detecting unit including an ink-detecting chamber, a moving member, and a detecting section. The ink-detecting chamber may include an ink inlet, an ink outlet, a flexible diaphragm that is displaced in response to the ink pressure between the ink inlet and the ink outlet, and a detecting-section mounting surface facing the diaphragm. The volume of the ink-detecting chamber may vary with the ink pressure. The moving member may be disposed in the ink-detecting chamber so as to move together with the diaphragm. The detecting section may be disposed on the detecting-section mounting surface and may include the ink-end sensor and a detecting space portion communicating with the ink-detecting chamber. The ink-end sensor may be a piezoelectric sensor that applies a vibration to the detecting space portion and detects a waveform of residual vibration following the vibration.

In the above printing apparatus, preferably, the ink-end sensor detects the amplitude or frequency of the waveform of residual vibration on the basis of the distance between the ink-end sensor and the moving member.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

FIG. **1** is a top view of a printing apparatus according to an embodiment of the invention.

FIG. **2** is a control block diagram of the printing apparatus according to the embodiment.

FIG. **3** is a characteristic graph showing the relationship between determination results from a determining unit and ink pressure in an ink cartridge.

FIG. **4** is a characteristic graph showing how an ink-end sensor detects an ink-end point.

FIG. **5** is a diagram illustrating pressure loss and water head difference in a flow channel extending from the ink cartridge to a recording head via an ink channel.

FIG. **6** is a flowchart of a cleaning process.

FIG. **7** is an exploded perspective view of the ink cartridge.

FIG. **8** is an exploded perspective view of an ink-detecting unit shown in FIG. **7**.

FIG. **9** is a schematic perspective view of a unit body shown in FIG. **7** with a moving member and a spring accommodated therein.

FIG. **10** is a sectional view of the ink-detecting unit with an ink pack being full.

FIG. **11** is a sectional view of the ink-detecting unit with the ink pack being empty.

FIG. **12**A is a characteristic graph showing a waveform of residual vibration with a smaller attenuation.

FIG. **12**B is a characteristic graph showing a waveform of residual vibration with a larger attenuation.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

An ink-jet recording apparatus according to an embodiment of the invention will now be described with reference to the drawings. The embodiment described below does not unduly limit the scope of the invention in the appended claims, and not all elements described in the embodiment are essential for the invention.

Structure of Printing Apparatus

FIG. **1** is a top view of the printing apparatus according to the embodiment of the invention. In FIG. **1**, a carriage **1** is driven by a carriage motor **3** via a timing belt **2** and is guided by a guiding member **4** so that it reciprocates in the longitudinal direction of a paper-guiding member **5**. A first recording head **7** and a second recording head **8** are mounted on a surface of the carriage **1** opposite recording paper side by side in the direction in which the carriage **1** moves.

In addition, subtank units **10** and **11** with a damper function for supplying ink to the first and second recording heads **7** and **8** are mounted on the top surface of the carriage **1**. These subtank units **10** and **11** are supplied with different inks from ink cartridges (not shown) via ink supply tubes **9**.

In addition, a cleaning mechanism **20** for cleaning the recording heads (e.g., ink-jet heads) **7** and **8** are provided in a non-printing region on the pathway along which the recording heads **7** and **8** move. The cleaning mechanism **20** is a generic name for members **12** to **19** to be described below.

The cleaning mechanism **20** includes a capping unit **12** for sealing surfaces of the recording heads **7** and **8** in which nozzles are disposed, namely, nozzle plates, in the non-printing region.

The capping unit **12**, as shown in FIG. **1**, includes cap members **13** and **14** that move vertically to seal the recording heads **7** and **8**, respectively, as the carriage **1** moves into the non-printing region.

A negative pressure simultaneously applied to the cap members **13** and **14** by driving a pump unit **15** drains ink from nozzle orifices of the recording heads **7** and **8** into the cap members **13** and **14**. This causes bubbles and dust near the nozzle surfaces of the recording heads **7** and **8** to be sucked into the cap members **13** and **14**.

The ink drained into the cap members **13** and **14** is sucked into tubes **16** and **17** and is drained into waste ink tanks **18** and **19**.

Control Block

FIG. **2** is a control block diagram of the printing apparatus according to this embodiment. In FIG. **2**, an ink required for printing is supplied from an ink cartridge **100** having an ink-end sensor **235** into the recording heads **7** and **8** via an ink channel **30**.

As the cleaning mechanism **20**, FIG. **2** shows only the driving system described above, namely, the capping unit **12**, the pump unit **15**, and the waste ink tanks **18** and **19**. The capping unit **12** and the pump unit **15** are controlled by a control unit **32**.

A detecting unit **34** detects a cleaning or printing command issued by pushing a switch or setting a timer and transmits it to a determining unit **36**. If different types of cleaning are available, the detecting unit **34** determines the type of cleaning on the basis of cleaning specification. The determining unit **36** determines whether or not a cleaning or printing operation is permitted on the basis of information concerning ink level from the ink-end sensor **235** of the ink cartridge **100** and a cleaning or printing command.

If the determining unit **36** permits the cleaning or printing operation, it directs the control unit **32** to start the operation.

The ink cartridge **100** in this embodiment supplies the ink under pressure. A pressurizing unit **38** constantly keeps an ink pack in the ink cartridge **100** under pressure unless the printing apparatus is in a suspend mode.

If the determining unit **36** prohibits the cleaning or printing operation, on the other hand, it provides notification requesting replacement of the ink cartridge **100** for a display panel **40** and an LED **42**.

If the determining unit **36** notifies the control unit **32** of starting of a cleaning operation, the control unit **32** moves the recording heads **7** and **8** to a cleaning position, moves the capping unit **12** to the nozzle surfaces to cap them, and drives the pump unit **15** to suck waste ink.

Determining Unit

The determining unit **36** in this embodiment permits starting of a printing or cleaning operation in response to a command issued before the ink-end sensor **235** detects an ink-end point and prohibits starting of a printing or cleaning operation in response to a command issued after the ink-end sensor **235** has detected the ink-end point.

The setting of the ink-end point required for the determination will now be described with reference to FIGS. **3** and **4**. FIG. **3** is a graph showing the relationship between determination results from the determining unit **36** and the ink pressure in the ink cartridge **100**. FIG. **4** is a graph showing how the ink-end sensor **235** detects the ink-end point.

FIG. **3** shows the relationship between the ink pressure in the ink cartridge **100** and the ink level. The ink pressure decreases with decreasing ink level. FIG. **4** shows the relationship between the ink pressure in the ink cartridge **100** and the amplitude V or frequency f of residual vibration output from the ink-end sensor **235**, as described later.

In this embodiment, when the ink pressure decreases to a first pressure P_G shown in FIG. **3**, the output (amplitude V or frequency f) of the ink-end sensor **235** reaches a threshold, as shown in FIG. **4**, so that the ink-end sensor **235** detects the ink-end point.

In this embodiment, the first pressure P_G, corresponding to the ink-end point detected by the ink-end sensor **235**, is set to the minimum pressure near an outlet of the ink cartridge **100** at which the recording heads **7** and **8** can print an image of predetermined quality.

As shown in FIG. **3**, the determining unit **36** permits starting of a printing or cleaning operation in response to a command issued at time ta before time t**0**, at which the ink-end sensor **235** detects the ink-end point (first pressure P_G). In this case, the cleaning or printing operation may end after time t**0**, at which the ink-end sensor **235** detects the ink-end point. The determining unit **36**, on the other hand, prohibits starting of a printing or cleaning operation in response to a command issued at time tb after time t**0**, at which the ink-end sensor **235** detects the ink-end point. The determining unit **36** can thus determine whether or not starting of a printing or cleaning operation is permitted at a low ink level with respect to the ink-end point based on the ink pressure, which correlates with the ink level, without depending on a soft counter or dot counter.

The maximum amount of ink consumed in cleaning or printing of predetermined unit does not exceed the difference between ink levels B and A (B−A) in FIG. **3** so that a cleaning or printing operation started before the ink pressure reaches the first pressure P_G ends before time tc, at which the ink pressure reaches a second pressure P_M at which ink-ejection operation should be prohibited. The determining unit **36**, on the other hand, prohibits a cleaning or printing operation started after time t**0**, at which the ink pressure reaches the first pressure P_G, and requests replacement of the ink cartridge **100** because the operation could end after time tc, at which the ink pressure reaches the lower limit pressure of second pressure P_M.

The lower limit pressure of second pressure P_M is the critical pressure at which menisci do not collapse at the nozzle surfaces of the recording heads **7** and **8** and no air intrudes; the ink ejection operation cannot be performed below the second pressure P_M. The menisci are surface state of ink at the nozzle, which are made by boundary tension of the ink.

In this embodiment, as described above, the determining unit **36** determines whether or not starting of a cleaning or printing operation of the predetermined printing unit is permitted only on the basis of time t**0**, at which the ink-end sensor **235** detects the ink-end point, and the time at which a cleaning or printing command is issued. Unlike the related art, therefore, the determination can be performed without depending only on a soft counter or dot counter, which would cause a cumulative error, so that an unnecessary amount of ink does not remain in the ink cartridge **100** at the time of replacement.

In addition, because the ink pressure in the ink cartridge **100** correlates with the ink level, as shown in FIG. **3**, and the ink-end sensor **235** detects the ink-end point on the basis of the ink pressure, as shown in FIG. **4**, the ink-end sensor **235** can precisely detect the first pressure P_G (ink-end detection pressure), on which the determining unit **36** depends for its determination. This advantage cannot be achieved by the method using a mechanical sensor according to Patent Document 4.

First and Second Pressures

Next, the first and second pressures P_G and P_M will be described with reference to FIG. **5**. FIG. **5** is a diagram illustrating pressure loss and water head difference in the flow channel extending from the ink cartridge **100** to the recording heads **7** and **8** via the ink channel **30**. In this embodiment, as shown in FIG. **5**, the ink channel **30** has a valve that opens when a predetermined negative pressure is reached on the recording head side, for example, a pressure-reducing valve **31**, upstream of the recording heads **7** and **8**. Even though the pressure in the ink supply channel up to the pressure-reducing valve **31** upstream of the recording heads **7** and **8** varies with the ink level of the ink cartridge **100**, the effect of such variations on the recording head side can be eliminated by the pressure-reducing valve **31**.

In this embodiment, the first pressure P_G, which is set to ensure image quality, is calculated from the maximum pressure loss ($-\Delta P_1$) in the flow channel from the outlet of the ink cartridge **100** to the center of the valve **31** in printing and the water head difference 1 ($-\Delta H_1$) between the outlet of the ink cartridge **100** and the center of the valve **31**, as reference level of the water head is a level of the nozzle surface. That is, the first pressure P_G is calculated by the following equation:

$$\text{first pressure } (P_G)=|\text{maximum pressure loss } (-\Delta P_1)+\text{water head difference 1 } (-\Delta H_1)|$$

Hence, if the pressurizing unit **38** shown in FIG. **2** pressurizes the ink in the ink cartridge **100** to the extent that the pressure near the outlet (supply port) of the ink cartridge **100** exceeds the first pressure P_G, the ink can be constantly pumped to the valve **31** without a deficiency of ink supply even under the effects of the pressure loss and the water head difference in the ink channel **30** in FIG. **5**. This allows the recording heads **7** and **8** to constantly eject droplets of predetermined size, thus ensuring print quality. Accordingly, the first pressure P_G can be used as the ink-end point to ensure print quality by prohibiting starting of a printing operation after detecting the ink-end point.

The maximum pressure loss in the flow channel in printing is the channel loss at the maximum flow rate and in a low temperature range, in which the ink viscosity is maximized. The maximum pressure loss is calculated by the equation $-\Delta P_1=Q_1\times R_1$ (Pa), where Q_1 (m^3/s) is the maximum flow rate in printing and R_1 ($Pa\cdot s/m^3$) is flow resistance.

Although the first pressure P_G may be calculated as described above, it may instead be determined in practical printing by monitoring the minimum pressure near the outlet (supply port) of the ink cartridge **100** at which dots can be printed with predetermined print quality. Alternatively, the output of the ink-end sensor **235** built into the ink cartridge **100** may be monitored. In this case, the first pressure P_G is set on the basis of the output of the ink-end sensor **235**, which detects the first pressure P_G as the ink-end point, so that no correction is required for factors such as the channel loss in the pathway to the ink-end sensor **235** and the outlet (supply port **109**) of the ink cartridge **100**. In other cases, the end-point pressure can be set by correcting the first pressure P_G on the basis of the factors such as the channel loss in the pathway to the ink-end sensor **235** and the outlet (supply port **109**) of the ink cartridge **100**.

Next, the second pressure P_M will be discussed. The lower limit pressure of second pressure P_M, as described above, is the pressure near the outlet of the ink cartridge **100** below which menisci collapse at the nozzle surfaces of the recording heads **7** and **8**. The pressure on the recording head side at which the valve **31** shown in FIG. **5** opens is usually set to a pressure higher than the pressure at which the menisci collapse at the recording heads **7** and **8**. Hence, the pressure range below the first pressure P_G includes a range in which the pressure in the flow channel on the ink cartridge side of the valve **31** is lower than the pressure at which the valve **31** opens and in which the valve **31** remains open. In this state, if the menisci collapse at the nozzles of the recording heads **7** and **8** after cleaning, contaminated ink drained from the nozzles of the recording heads **7** and **8** into the capping unit **12** shown in FIGS. **1** and **2** flow back together with air along the ink channel **30** because the valve **31** remains open. This backflow continues until the pressure in the ink channel **30** increases to the pressure at which the menisci are restored.

This is a phenomenon that manufacturers must avoid because it would complicate maintenance of the recording heads **7** and **8** and the ink channel **30**. In this embodiment, therefore, the determination of whether or not starting of a printing or cleaning operation is permitted is made with respect to the first pressure P_G so that the pressure near the outlet of the ink cartridge **100** does not reach the second pressure P_M at the end of the operation.

The lower limit pressure of second pressure P_M, which is set to prevent the menisci from collapsing, is calculated from the meniscus strength ($+\Delta H_3$) of the nozzles of the recording heads **7** and **8** and the water head difference 2 ($-\Delta H_2$) between the outlet of the ink cartridge **100** and the nozzle surfaces of the recording heads **7** and **8**, The meniscus strength is called water down difference of menisci, which is pressure at the menisci are disappear. That is, the second pressure P_M is calculated by the following equation:

$$\text{second pressure } (P_M)=|\text{meniscus strength } (+\Delta H_3)+\text{water head difference 2 } (-\Delta H_2)|$$

To permit ink ejection from the recording heads **7** and **8** during a cleaning operation (flushing) or printing after cleaning (without ensuring image quality), the second pressure P_M is calculated from the meniscus strength ($+\Delta H_3$) of the nozzles of the recording heads **7** and **8**, the maximum pressure loss ($-\Delta P_2$) in the flow channel from the outlet of the ink cartridge **100** to the nozzles of the recording heads **7** and **8** in printing, and the water head difference 2 ($-\Delta H_2$) between the outlet of the ink cartridge **100** and the nozzle surfaces of the recording heads **7** and **8**. That is, the second pressure P_M is calculated by the following equation:

$$\text{second pressure } (P_M)=|\text{meniscus strength } (+\Delta H_3)+\text{maximum pressure loss } (-\Delta P_2)+\text{water head difference 2 } (-\Delta H_2)|$$

In FIG. **3**, the amount of ink (B−A) corresponding to the difference between the first pressure P_G and the second pressure P_M is greater than or equal to the maximum amount of ink (Q) consumed in cleaning ($Q\leqq B-A$). In this case, if the determining unit **36** permits starting of a cleaning operation in response to a command issued at time ta before time **t0**, at which the ink-end sensor **235** detects the ink-end point (first pressure P_G), the lower limit pressure of second pressure P_M is not reached before the operation ends.

Cleaning Process

Next, a cleaning process according to this embodiment will be described with reference to FIG. **6**. In FIG. **6**, the ink-end sensor **235** built into the ink cartridge **100** detects whether or not the ink-end point has been reached (Step S**1**). Next, the determining unit **36** shown in FIG. **2** determines whether or not an ink-end-sensor flag has been set in, for example, the determining unit **36** (Step S**2**). The ink-end-sensor flag is set in, for example, a storage section of the determining unit **36** when the ink-end sensor **235** detects the ink-end point.

If the determination in Step S**2** is "YES", the process proceeds to Step S**3**; if it is "NO", the process proceeds to Step S**4**. In Step S**3**, in which an error has occurred, the determining unit **36** prohibits starting of a cleaning operation even if a cleaning command has been issued.

In Step S**4**, the determining unit **36** checks protective counters for the waste ink tanks **18** and **19**. The protective counters mean, for example, that the determining unit **36** performs soft counting on the basis of the amount of ink consumed in cleaning and the number of cleaning operations. On the basis of the protective counts, the determining unit **36** determines whether or not the waste ink tanks **18** and **19** are full (Step S**5**).

If the determination in Step S**5** is "YES", the process proceeds to Step S**6**; if it is "NO", the process proceeds to Step S**7**. In Step S**6**, in which an error has occurred, the determining unit **36** prohibits starting of a cleaning operation even if a cleaning command has been issued because one of the waste ink tanks **18** and **19** is full.

In Step S**7**, the determining unit **36** determines whether or not an error has been occurred in Step S**3** or S**6**. If the determination in Step S**7** is "YES", the determining unit **36** prohibits starting of a cleaning operation; if it is "NO", the determining unit **36** permits starting of a cleaning operation.

Ink Cartridge

Next, an example of the ink cartridge **100** will be described. FIG. **7** is an exploded perspective view of the ink cartridge **100**. The ink cartridge **100** is attached to a cartridge-mounting section of the above printing apparatus so as to be detachable therefrom. In FIG. **7**, the ink cartridge **100** includes a container body **105** having a pressurizing chamber **103** into which a pressurizing fluid is introduced from the pressurizing unit **38** shown in FIG. **2**; an ink pack **107** storing an ink that is discharged through an ink-introducing member **107***a* when pressurized by the pressurizing chamber **103**; an ink supply port **109** through which the ink is supplied to the recording heads **7** and **8** of the printing apparatus; and an ink-detecting unit **111** disposed between the ink pack **107** and the ink supply port **109** to detect the ink level.

The container body **105** includes a pack-accommodating section **103***a* and a detecting-unit accommodating section **113** accommodating the ink-detecting unit **111**.

An opening plane of the pack-accommodating section **103***a* is sealed with a sealing film **115** after the ink pack **107** is accommodated therein so that the pressurizing chamber **103** is hermetically sealed. A partition **105***a* separating the detecting-unit accommodating section **113** from the pack-accommodating section **103***a* has a pressurizing port **117** through which the pressurizing fluid is supplied into the pressurizing chamber **103**. After the ink cartridge **100** is attached to the printing apparatus, the ink pack **107** can be pressurized via the pressurizing port **117** and the pressurizing chamber **103**.

The cylindrical ink-introducing member **107***a* is joined to one end of a flexible pack member **107***b* of the ink pack **107**. A connection needle **111***a* of the ink-detecting unit **111** is inserted into and connected to the ink-introducing member **107***a*. The ink-introducing member **107***a* of the ink pack **107** is hermetically inserted into a connection-port insertion opening **118** formed in the partition **105***a*. A leading end of the ink-introducing member **107***a* protrudes into the detecting-unit accommodating section **113**. The ink pack **107** is filled with a highly degassed ink and is sealed with a sealing film **108** before being connected to the ink-detecting unit **111**. After the ink pack **107** is attached to the pack-accommodating section **103***a*, resin spacers **119** are attached to front and rear sloped portions **107***c* and **107***d* of the flexible pack member **107***b*. This prevents the ink pack **107** from becoming unstable against impacts and vibrations inside the pack-accommodating section **103***a*.

When the ink-detecting unit **111** is attached to the detecting-unit accommodating section **113**, the connection needle **111***a* pierces the sealing film **108** and actuates a valve mechanism (not shown) provided in the ink-introducing member **107***a* to allow the ink to be introduced therefrom.

A resin cover **121** is disposed on the detecting-unit accommodating section **113** and the sealing film **115**. When the cover **121** is disposed on the container body **105**, engaging members (not shown) engage with engaging portions **122** of the container body **105** so that the cover **121** is fixed to the container body **105**.

Ink-Detecting Unit

FIG. **8** is an exploded perspective view of the ink-detecting unit **111**. FIG. **9** is a schematic perspective view of the ink-detecting unit **111** after assembly with its diaphragm omitted. FIG. **10** is a sectional view of the ink-detecting unit **111** with the ink pack **107** being full. FIG. **11** is a sectional view of the ink-detecting unit **111** with the ink pack **107** being empty. FIGS. **10** and **11** are sectional view taken along a flow channel formed across a moving member **210** between an ink inlet **204** and an ink outlet **205**.

The ink-detecting unit **111** in this embodiment detects the ink level while the ink flows into an ink-detecting chamber **202** (see FIGS. **8**, **9**, and **10**) via the connection needle **111***a* (see FIGS. **7** and **8**) and the ink inlet **204** (see FIGS. **9** and **10**) on the backside of a unit body **200** and flows out via the ink outlet **205** (see FIG. **10**) and an ink-introducing member **111***b* (see FIGS. **8** and **9**). A sealing film **211***c* shown in FIG. **7** seals an outlet of the ink-introducing member **111***b* in a liquid-tight manner. When the ink cartridge **100** is attached to the printing apparatus, an ink-introducing needle of the printing apparatus pierces the sealing film **211***c* to enter the ink-introducing member **111***b*.

The ink-detecting unit **111**, as shown in FIG. **8**, includes the unit body **200**, the moving member **210**, a torsion coil spring **220**, and a diaphragm **201** sealing the unit body **200**. The moving member **210** is disposed in a recess **203** of the unit body **200**.

As shown in FIG. **10**, the ink inlet **204** is disposed at one end of the recess **203** of the unit body **200** in the longitudinal direction, and the ink outlet **205** is disposed at the other end of the recess **203**. The ink inlet **204** communicates with the connection needle **111***a* (see FIGS. **7** and **8**) of the ink-detecting unit **111**.

The moving member **210** pivots about a pivot shaft **211** in the ink-detecting chamber **202**. A pressure-receiving plate **212** is disposed at a position on the moving member **210** away from the pivot shaft **211**. The top surface **212***b* of the pressure-receiving plate **212** faces the diaphragm **201**.

The pressure-receiving plate **212** has a first flow channel **215** through which the ink flows from the ink inlet **204** into a detecting space portion **234**, as described later, and a second flow channel **216** through which the ink flows from the detecting space portion **234** into the ink outlet **205**. As shown in FIGS. **8** and **10**, the portions of the first and second flow channels **215** and **216** in the top surface **212***b* of the pressure-receiving plate **212** are formed by sealing openings **215***a* and **215***b* in the top surface **212***b* of the pressure-receiving plate **212** with the diaphragm **201**.

The pressure-receiving plate **212** of the moving member **210** is biased in the direction indicated by arrow A in FIGS. **10** and 11 by the torsion coil spring **220**, which serves as an example of a biasing member. The diaphragm **201** is attached to the unit body **200** and the pressure-receiving plate **212** of the moving member **210** by heat welding.

As the ink pressure in the ink-detecting chamber **202** varies, the moving member **210** pivots and displaces the pressure-receiving plate **212**. The displacement of the pressure-receiving plate **212** is accompanied by displacement of the diaphragm **201** attached to the pressure-receiving plate **212**, thus changing the volume of the ink-detecting chamber **202**.

Ink-Detecting Section

As shown in FIGS. **10** and **11**, an ink-detecting section **230** of the ink-detecting unit **111** includes the detecting space portion **234**, which includes ink-guiding channels **231** and **232** extending through a bottom wall **208***a* of the unit body **200** and an ink-guiding channel **233** communicating with the ink-guiding channels **231** and **232**. The ink-detecting section **230** also includes the ink-end sensor **235**, for example, a piezoelectric sensor, which is disposed adjacent to the detecting space portion **234** so as to define the detecting space portion **234** with the bottom wall **208***a*. The ink-end sensor **235** applies a vibration to the detecting space portion **234** and detects the waveform of residual vibration following that vibration.

The ink-end sensor **235** can detect different waveforms of residual vibration depending on whether or not the pressure-receiving plate **212** covers the ink-guiding channels **231** and **232**. The detection mechanism is disclosed in Patent Document 1.

For example, a waveform of residual vibration shown in FIG. **12**A is observed if the ink-end sensor **235** applies a vibration to the detecting space portion **234** while the ink is being supplied from the ink pack **107** under pressure, as shown in FIG. **10**. On the other hand, for example, a waveform of residual vibration shown in FIG. **12**B is observed if the ink-end sensor **235** applies a vibration to the detecting space portion **234** while no ink is being supplied from the ink pack **107**, as shown in FIG. **11**. Thus, the waveform of residual vibration differs in attenuation depending on the distance from the ink-end sensor **235** to the rigid pressure-receiving plate **212**. Hence, the ink-end state of the ink pack **107** in FIG. **11** can be distinguished from that in FIG. **10** by, for example, comparing with the threshold shown in FIG. **4** the amplitude of the waveform of residual vibration at the time when a predetermined period of time elapses after the ink-end sensor **235** applies a vibration. This detection may instead be performed by counting the duration of residual vibration or the frequency of the waveform of residual vibration.

In this embodiment, the ink-end sensor **235** detects the ink-end point, which indicates that the ink in the ink pack **107** has been depleted, by detecting the waveform of residual vibration observed in the state of FIG. **11**. In this case, the ink pressure corresponding to the ink-end point is set to the first pressure P_G, as shown in FIG. **4**, to ensure image quality.

While the embodiment has been described in detail above, it will readily be appreciated by those skilled in the art that various modifications are possible without substantially departing from the new matters and advantages of the invention; therefore, such modifications are all included in the scope of the invention. For example, terms used together with different broader or synonymous terms at least once in the specification or the drawings can be replaced with those different terms in any section of the specification and the drawings.

The entire disclosure of Japanese Patent Application No. 2008-039670, filed Feb. 21, 2008 is expressly incorporated by reference herein.

What is claimed is:

1. A printing apparatus comprising:

a recording head that prints an image in response to a printing command;

an ink cartridge communicating with the recording head and storing an ink to be supplied to the recording head;

an ink channel extending between the recording head and the ink cartridge;

a cleaning mechanism that cleans the recording head with the ink stored in the ink cartridge in response to a cleaning command; and

a determining unit that determines whether or not the recording head is permitted to start a printing operation and whether or not the cleaning mechanism is permitted to start a cleaning operation on the basis of the ink level of the ink cartridge;

the ink cartridge including:

an ink pack from which the ink is introduced under pressure; and

an ink-end sensor that detects an ink-end point on the basis of the pressure of the ink supplied from the ink pack under pressure;

wherein the ink pressure corresponding to the ink-end point detected by the ink-end sensor is set to a first pressure that is the minimum pressure near an outlet of the ink cartridge at which the recording head can print an image of predetermined quality; and

the determining unit permits starting of a printing or cleaning operation in response to a command issued before the ink-end sensor detects the ink-end point and prohibits starting of a printing or cleaning operation in response to a command issued after the ink-end sensor has detected the ink-end point.

2. The printing apparatus according to claim **1**, wherein the ink channel includes a pressure-reducing valve upstream of the recording head; and

the first pressure is calculated from the maximum pressure loss between the outlet of the ink cartridge and the center of the pressure-reducing valve in printing and the water head difference between the outlet of the ink cartridge and the center of the pressure-reducing valve.

3. The printing apparatus according to claim **1**, wherein the first pressure is higher than lower limit of a second pressure near the outlet of the ink cartridge below which a meniscus collapses in the recording head; and

the amount of ink that can be supplied from the ink cartridge while the ink pressure changes from the first pressure to the lower limit of second pressure is greater than or equal to the amount of ink consumed in cleaning.

4. The printing apparatus according to claim **3**, wherein the second pressure is calculated from the water down difference of menisci of a nozzle of the recording head, the maximum pressure loss between the outlet of the ink cartridge and the recording head in printing, and the water head difference between the outlet of the ink cartridge and an outlet of the recording head.

5. The printing apparatus according to claim **1**, wherein the ink cartridge includes an ink-level detecting unit including:

an ink-detecting chamber including an ink inlet, an ink outlet, a flexible diaphragm that is displaced in response to the ink pressure between the ink inlet and the ink outlet, and a detecting-section mounting surface facing the diaphragm, the volume of the ink-detecting chamber varying with the ink pressure;

a moving member disposed in the ink-detecting chamber so as to move together with the diaphragm; and

a detecting section disposed on the detecting-section mounting surface and including the ink-end sensor and a detecting space portion communicating with the ink-detecting chamber, the ink-end sensor being a piezoelectric sensor that applies a vibration to the detecting space portion and detects a waveform of residual vibration following the vibration.

6. The printing apparatus according to claim **5**, wherein the ink-end sensor detects the amplitude or frequency of the waveform of residual vibration on the basis of the distance between the ink-end sensor and the moving member.

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